$$E_b/(N_o+B_o+\Sigma I_{oi}) = S/\{L_m R_b\,[N_o+1.2(MS/W_{DS})[1+\Sigma(F_{ci}F_{pi}/F_{bi})]\} \qquad (45)$$

Solving Eq. (45) for M, defining $N_o+B_o+\Sigma I_{oi}$ to be N_{oT}, and setting E_b/N_{oT} equal to its minimum acceptable value of $(E_b/N_o)_{min}$, the realizable uplink capacity M_{ru} measured in voice channels per beam per 2.56 MHz equals

$$M_{ru} = \{W_{DS}/h_v R_b (E_b/N_o)_{min} L_m\}\{1/[1.2(1+\Sigma F_{ci}F_{pi}/F_{bi})]\} \qquad (46)$$

$$=\{C_{MIU}/L_m\}\{1/[1.2(1+\Sigma F_{ci}F_{pi}/F_{bi})]\} = C_{MRU}/[1.2(1+\Sigma F_{ci}F_{pi}/F_{bi})]$$

This completes the development of the mathematical basis on which the uplink capacity of the Constellation system is based. The results of the development are applied in the next section to estimate the uplink capacity of the Constellation system in an interference-sharing environment.

4.2.2 Calculation of Inbound Uplink Capacity

Using Eqs. (40) and (41), the maximum ideal upper bound of the L-band uplink capacity in voice channels per beam per 2.56 MHz equals

$$C_{MIU} = [W_{DS}/h_v R_b]/[(E_b/(N_o+B_o)_{min}] \qquad (47)$$

Calculation of C_{MIU} merely represents an initial step in the analysis process and is only marginally related to the expected or realizable uplink capacity. The value of $E_b/(N_o+B_o)_{min}$, which in the analysis is measured at the input to the amplifier in the repeater satellite, equals the minimum theoretical value of 2.8 dB needed at the gateway demodulator, as discussed in section 4.1.1, plus an assumed degradation of .25 dB introduced by the feeder link, a despreading loss of 1 dB, and a demodulator loss assumed to be .25 dB. The value of the term $E_b/(N_o+B_o)_{min}$ applicable to Eq. (45) is therefore 4.3 dB or 2.69. Other losses such as satellite translation loss and the gateway receiver loss are common to both the power in the desired signal and the power in the unwanted signals. With W_{DS} equal to 2.56 MHz, R_b equal to 5 kbits/sec, and a voice activity factor of 1/2, the C_{MIU} equals 380.67 voice channels per beam per 2.56 MHz. The corresponding maximum ideal CONUS uplink capacity is 40 times this value or 15,227 voice channels.

To compensate for several random system uncertainties which otherwise reduce the power in the desired signal, a link margin totaling L_m is introduced and the corresponding lower capacity is called the maximum realizable uplink capacity C_{MRU}, which Eq. (42) estimates to be

$$C_{MRU} = C_{MIU}/L_m = 15{,}227/L_m \tag{48}$$

With 3.5 dB of fixed margin, L_m equals 2.24 and the maximum realizable uplink capacity equals 15,227/2.24 or 6,798 CONUS voice channels.

The best estimate of the actual capacity achievable on the uplink is called the realizable uplink capacity estimated by Eq. (46) to be

$$M_{ru} = C_{MRU}/[1.2(1+\Sigma F_{ci}F_{pi}/F_{bi})] = 6{,}798/[1.2(1+\Sigma \beta_i F_{ci}F_{pi}/F_{bi})] \tag{49}$$

where the β_i are the polarization isolation factors discussed in the Final Majority Report and introduced in section 4.1.2 as having values of either .4 or 1.

Equation (49) will now be used to estimate the realistic capacity of the Constellation system uplink. First of all, when the band is not shared with any other system, the maximum realizable uplink capacity equals about 6,798/1.2 or 5,665 voice channels.

The impact of sharing the band with other systems is not so easy to estimate. If the other three systems were just like the Constellation system and no polarization isolation was used, the M_{ru} would equal 6,798/[1.2(4)] or 1,416 CONUS voice channels. If the Constellation system deploys second, and polarization isolation is used, and each system is just like the Constellation system, the maximum realizable uplink capacity would equal 6,798/[1.2(1+.4+.4+1)] or 2,023 CONUS voice channels.

Recalling that F_{ci}, F_{pi}, and F_{bi} are the capacity, power, and bandwidths of the ith interfering system relative to the Constellation system, it would not be unreasonable to expect an interference case in which F_{c1}, F_{c2}, and F_{c3} were respectively 6, 2, 1, and F_{p1}, F_{p2}, and F_{p3} were respectively .1, .5, 1, and F_{b1}, F_{b2}, and F_{b3} were .5, 1, 1. Then if the Constellation system deploys second, the M_{ru} capacity in CONUS voice channels equals

$$M_{ru} = 6{,}798/[1.2(1+.4(6)(.1)/.5+.4(2)/1+1(1)(1)/1)] = 1{,}727 \tag{50}$$

The estimates of uplink capacity for the various cases are summarized in Table B-4. Again the decrease in capacity when even one additional system shares the band is very substantial. This reflects the results of our analyses which show the higher "efficiency" in terms of voice channels per MHz when the Constellation system operates in narrower band by itself.

Three Other Systems	Maximum Realizable Uplink Capacity (voice channels)
Maximum If Constellation Alone In the Band	5,665
Same as Constellation (without polarization isolation)	1,416
Same as Constellation (with polarization isolation)	2,023
Typical Mixed Case (with polarization isolation)	1,727

Table B-4. Predicted Maximum Realizable L-Band Uplink Capacity (Expected or Average Interference)

Table B-4 shows that the uplink CONUS capacity with polarization isolation appears to about 1700 to 2000 voice channels. Tables B-2 and B-3 suggest a downlink capacity range of 1200 to 1800. With the ability of the Constellation system to increase its uplink power to relatively high levels if needed, the downlink capacity is more likely to be the limiting factor in the capacity of the Constellation system. Therefore, the capacity of the system is expected to be at least 1200 voice channels, which is somewhat greater than the 1000 voice channels projected for the Constellation system operating in 2.56 MHz dedicated to its own use. The use of polarization isolation with an average isolation factor of -4 dB is critical in achieving this predicted capacity. A fixed margin of 3.5 dB is also assumed. With the larger, heavier, and higher-powered satellites; increased launch costs; and more complicated and powerful subscriber units; even this somewhat higher level of traffic capacity may not generate adequate revenues to make the interference-sharing Constellation system economically viable.

5. Impact On Constellation Satellite Design and Cost

The results of the analysis in the previous section are consistent with the general results of the IWG-1 Majority Report. However, this analysis also shows that there is not a significant system capacity increase between Constellation's baseline satellite using 2.56 MHz without code noise interference from any other satellite in that band and the capacity of a Constellation satellite using four times this amount of spectrum but also experiencing code noise interference from three other systems.

However, there is a very significant impact on the design of a Constellation satellite that has to operate in an interference sharing environment. One significant impact is that the amount of feeder link spectrum is substantially increased. As shown in Appendix C, the 21 MHz of C-band feeder link spectrum required for Constellation's baseline satellite design using dual polarization increases to 78 MHz. Another very significant impact is that the total satellite transmitted power has to be increased by a factor of four in the S-band service downlink and the C-band feeder downlink. This has a substantial impact on the size and weight of the satellite because of the larger solar arrays and batteries needed to generate these high levels of total transmitted power. The communications payload design may also be more complicated if it is necessary to process the individual 2.56 MHz rf signal channels within the overall 11.35 MHz CDMA band segment rather than processing the 11.35 MHz band as a single rf channel. Finally, there may be significant impact on Constellation's subscriber units in an interference sharing environment in terms of an increase in equipment and signal processing complexity and required transmitter power.

Constellation performed a preliminary analysis to estimate the cost impact of these design changes. Constellation estimates that a satellite designed to operate across the Commission's proposed 11.35 MHz CDMA band segment with three other satellite systems on an interference-sharing basis would weigh about 88 % more than Constellation's baseline 2.56 MHz satellite design, and cost about 23 % more to manufacture. To establish an initial constellation of 48 satellites, the total launch costs would increase by a factor of 2 to 2.4 depending on launch configuration

Engineer's Certification

The undersigned hereby certify that they are technically qualified persons responsible for the preparation of the engineering information contained in this Appendix, that they have either prepared or reviewed the information contained herein, and that it is complete and accurate to the best of their knowledge.

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Eq. (9) can be solved for the number of simultaneous voice channels M equal to

$$M = PFSD_{max}\, W_{DS}\, A_e\, [1/(E_b/N_oT)]\, [1/L_mL_{fl}L_rL_{ds}L_{dem}][1/N_oTR_b] \qquad (10)$$

where the voice activity factor h_v, assumed to equal 1/2, has been introduced to account for the increased number of voice channels achieved when the transmitter processor exploits the statistical properties of spoken voice.

When the product $(E_b/N_oT)L_{fl}L_rL_{ds}L_{dem}$ is set equal to its minimum value $(E_b/N_oT)_{min}$, the number of users or simultaneous voice channels may be called the realizable downlink capacity which is actually achievable in the shared-interference environment. This realizable downlink capacity, denoted by M_{rd}, is given by

$$M_{rd} = PFSD_{max}\, W_{DS}\, A_e\, [1/(E_b/N_oT)_{min}]\, [1/L_m\, h_vN_oTR_b] \qquad (11)$$

$$= PFSD_{max}\, W_{DS}\, A_e\, [1/(E_b/N_o)_{min}]\, [1/L_m\, h_v(N_o+B_o+\Sigma\beta_iI_{oi})R_b] \qquad (12)$$

This concludes the development of the mathematical basis for calculating the capacity of the Constellation system in a shared-interference environment. The next section of the report shows that the capacity estimates using the formulas in the Final Majority Report agree closely with the estimates derived using the detailed formulas derived in this section.

4.1.2 Calculation of Outbound Downlink Capacity

The first step in calculating downlink capacity using the method of the Final Majority Report is to find what is called the maximum ideal downlink capacity, M_{mid}. Section 4.1.1 Eq. (6) derives an expression for M_{mid} equal to

$$M_{mid} = PFSD_{max}\, W_{DS}\, A_e\, [1/(E_b/N_o)_{min}]\, [1/h_v N_o R_b] \tag{13}$$

The value of $PFSD_{max}$ is currently set by regulation at -142 dBW/m^2-4kHz or -178 dBW/m^2-4kHz. The filtered direct sequence bandwidth W_{DS} equals the chipping rate of 2.56 MHz (64.1 dBHz), the effective area of the subscriber unit antenna at a gain of 3.5 dB is -25.9 dBm^2, the noise PSD N_o equals $K_B T_{ssu}$ which equals -204.1 dBW/Hz at an subscriber unit system temperature T_{ssu} of 280K, and R_b is the bit rate (with overhead) assumed to equal 5 kbits/sec or 37 dBbits/sec. At the required bit error rate of 10^{-3}, the minimum ideal E_b/N_o equals about 2.8 dB for a rate-1/2 convolutional code with constraint length 7 using soft Viterbi decoding with 6-8 bit quantization. This value is increased by the loss term $L_{fl} L_r L_{ds} L_{dem}$ to derive the value of $(E_b/N_o)_{min}$. The values of L_{fl}, L_r, L_{ds}, and L_{dem} are assumed to be .25, 1.5, 1, and .25 dB respectively bringing the total of this loss term to 3 dB. Hence, $(E_b/N_o)_{min}$ equals 5.8 dB or 3.8. The voice activity factor is assumed to equal 1/2. Substituting all values into Eq. (13) yields the maximum ideal downlink capacity of 281.84 simultaneous voice channels per beam per 2.56 MHz or

$$M_{mid} = 11{,}274 \text{ CONUS voice channels} \tag{14}$$

where the CONUS capacity is derived as follows. With each beam using four center frequencies to position four CDMA channels each having a bandwidth 2.56 MHz within the 11.35 MHz assigned, the total maximum ideal downlink capacity of the 10-beam satellite covering CONUS equals 281.84x40 or 11,274 voice channels.

This measure of capacity should be considered merely the first step in calculating the realizable down link capacity. In itself, it is an extremely overly optimistic upper bound on the capacity which may be achievable in practice. It is calculated here to compare it with the first step in the analysis method presented in the Final Majority Report.

In the Final Majority Report, the maximum ideal downlink capacity of a CONUS system is denoted by C_{MID} and its formula in terms of notation used in this report is as follows:

$$C_{MID} = 40\{[W_{DS}]/[h_v\, R_b\, (E_b/N_o)_{min}]\} \tag{15}$$

where the factor of 40 results from a total RF bandwidth of 4 times the W_{DS} bandwidth and the number of beams covering CONUS being equal to 10. Since 40 is the factor used to convert from per beam per 2.56 MHz capacity to the CONUS voice channels or conversations capacity, Eq. (15) shows that the Final Majority Report formula in terms of voice channels per beam per 2.56 MHz would be given by the following:

$$C_{MID} = W_{DS}/[h_v\, R_b (E_b/N_o)_{min}] \tag{16}$$

Comparing Eq. (16) with Eq. (13) it is clear that the relationship between C_{MID} in the Final Majority Report and M_{mid} derived above is

$$M_{mid} = C_{MID} [PFSD_{max} A_e/N_o] \qquad (17)$$

This means that M_{mid} and C_{MID} are equal when the received signal Power Spectral Density (PSD) in Watts/Hz given by $[PFSD_{max} A_e]$ equals the noise PSD N_o. With the values used above $[PFSD_{max}$ Ae] equals -203.9 dBW/Hz and the noise PSD N_o equals -204.1 dB. Hence, predictions based on the method of the Final Majority Report are essentially equal to those derived using Eq. (13). However, the close agreement is more or less an accident since the signal density and the noise density may not always be so close to being equal.

A more realistic, but still not completely accurate, estimate of the down link capacity is the maximum realizable downlink capacity M_{mrd}. The Final Majority Report calls the result of this second step in the capacity calculation the realistic capacity C_{MRD} and it equals

$$C_{MRD} = C_{MID}/L_m \qquad (18)$$

where L_m is the total of the margins defined following Eq. (6) above. Comparing Eq. (18) with Eq. (7) it is clear that for equal margins the estimates of maximum realizable downlink capacity using the equations of section 4.1.1 will agree with the methods of the Final Majority Report to the degree that C_{MID} equals M_{mid}.

To continue following the steps of the Final Majority Report, assume that the margin for propagation impairments, deviation from an ideal isoflux satellite antenna, and variation from ideal power control together as they randomly take on different values require a margin of 3.5 dB. Then, L_m equals 3.5 dB or a factor of about 2.24. Hence, using Eq. (7) and M_{mid} (essentially equal to C_{MID}) the maximum realizable downlink is 1/2.24 the values of the maximum ideal downlink capacity derived earlier. Using Eq. (14) M_{mrd}, essentially equal to C_{MRD}, is given by

$$M_{mrd} = M_{mid}/L_m = 11{,}274/2.24 = 5036 \approx C_{MRD} \quad (19)$$

The Final Majority Report calls the best estimate of the achievable downlink capacity the realizable downlink capacity and denotes it by C_{RD}. Equation (12) denotes this realizable capacity by M_{rd} and gives its value as

$$M_{rd} = PFSD_{max}\, W_{DS}\, A_e\, [1/(E_b/N_{oT})_{min}]\, [1/L_m\, h_v N_{oT} R_b] \quad (20)$$

which can be rewritten using Eqs. (6) and (7) in the form

$$\begin{aligned} M_{rd} &= \{PFSD_{max}\, W_{DS}\, A_e\, [1/(E_b/N_o)_{min}]\, [1/h_v N_o R_b]\}[1/L_m] \\ &\quad \bullet [N_o/(N_o+B_o+\Sigma\beta_i I_{oi})] \\ &= [M_{mid}/L_m]\, [N_o/(N_o+B_o+\Sigma\beta_i I_{oi})] = M_{mrd}\, [N_o/(N_o+B_o+\Sigma\beta_i I_{oi})] \end{aligned} \quad (21)$$

The forms of Eq. (21) explain the convenience of initially calculating M_{mid} and M_{mrd}. Actually Eq. (21) looks simpler than it is. While N_o is easy to estimate, B_o and I_{oi} are not. As initial estimates, the following values are suggested.

The background Power Spectral Density (PSD) B_o equals $B_{oa}+B_{ob}+B_{oc}$, which are defined in section 4.1.1. B_{oa} comes from power transmitted by the same beam which is transmitting the desired signal power to the subscriber unit. The downlink codes within this beam are assumed to time synchronized to minimize self interference. The code power isolation factor a achieved using orthogonal Walsh codes of length 256 is assumed to equal .1. The power in the other beams which arrive at the desired subscriber unit via sidelobes and low antenna gain is not diminished by code orthogonality. But, the beam from at least one other satellite with high elevation angle having the desired subscriber unit in its high-gain *footprint* is assumed to have that beam or frequency channel shut off while servicing CONUS. Hence

$$B_o = \alpha B_{oa} + B_{ob} + B_{oc} \tag{22}$$

From Eq. (1) the total power in all signals transmitted by one satellite not wanted at a particular subscriber unit equals

$$S_i = [(M\text{-}1)/M]\,[P_t G_{tr}/4\pi D^2]\,[G_{rti}\lambda^2/4\pi]\,[1/L_r] \tag{23}$$

$$\approx [P_t G_{tr}/4\pi D^2]\,[G_{rti}\lambda^2/4\pi]\,[1/L_r] = PFSD_{max}\, W_{DS}\, A_e\,[1/L_r]$$

where the loss terms associated with signal despreading and demodulation has been deleted because the subscriber unit only demodulates its desired signal and the rest of the unwanted signals appear as noise. Hence, the B_{oa} contribution from the mainbeam of one satellite, recalling that L_r equals 1.5 dB, is given is given by

$$B_{oa} = S_i/W_{DS} = PFSD_{max}\, A_{ei}\,[1/L_r] = -205.4 \text{ dBW/Hz} \tag{24}$$

If the satellite antenna were to have a "rectangular" shaped footprint, i.e. one characterized by long and narrow beams with the long axis in the direction of satellite motion, there are at most two adjacent beams in the middle portion of the beam where the most overlap occurs and the interference appears to be greatest. The gain in these two adjacent beams is assumed to average at least 20 dB lower gain than the mainbeam and yield B_{ob} equal to $B_{oa}/10$. All of the rest of the power impinging on the subscriber unit emitted by all the rest of the Constellation satellites is assumed to average about 30 dB lower gain and yield B_{oc} equal to $B_{oa}/100$ or less. Therefore,

$$B_o = \alpha B_{oa} + B_{ob} + B_{oc} = .1B_{oa} + .1B_{oa} + .01\, B_{oa} = .21B_{oa} \tag{25}$$

$$= .21\text{x}10^{-20.54} = 6.1\text{x}10^{-22}\ \text{Watts/Hz}$$

The calculation of the interference caused by the other systems assumes that each satellite is transmitting the maximum allowed PFSD. In this case, as an initial approximation, what is B_{oa}, B_{ob}, and B_{oc} for our system is another systems I_{oai}, I_{obi}, and I_{oci} and vice versa. Therefore, for a worst case interference condition in which another system has two satellites in view at elevation angles of 25° or more, the PFSD equals -139 dBW/m^2-4kHz and I_{oai} equals -202.4 dBW/Hz, I_{obi} equals $I_{oai}/10$ or -212.4 dBW/Hz, and I_{oci} also equals $I_{oai}/100$ or -222.4 dBW/Hz. Under these assumptions I_{oi} of the ith interference-sharing system equals

$$I_{oi} = I_{oai} + I_{obi} + I_{oci} = I_{oai} + .1I_{oai} + .01I_{oai} = 1.11I_{oai} \tag{26}$$

$$= 1.11\text{x}10^{-20.24} = 6.39\text{x}10^{-21}\ \text{Watts/Hz}$$

Comparing the values of Eqs. (25) and (26) it is clear that each of the other systems has a substantial potential to interfere with the Constellation system. It may be necessary for the sharing Constellation system to transmit from two satellites to a subscriber unit and combine the signals coherently in order for the interference from other systems transmitting at -139 dBW/m^2-4kHz not to rapidly degrade the Constellation system capacity. Alternately, each other system could be limited to -142 dBW/m^2-4kHz and use just one satellite per subscriber unit as assumed here for the Constellation system.

The value of N_o is assumed to be -204.1 dBW/Hz or 3.89x10^{-21} Watts/Hz based on a subscriber unit receiver temperature of 280 K. Using Eq. (20), the expected realizable downlink capacity, M_{rd}, equals

$$M_{rd} = M_{mrd}/[1+(B_o/N_o)+\Sigma ß_i I_{oi}/N_o)] = M_{mrd}/[1.157 + 1.643\Sigma ß_i] \quad (27)$$

since B_o/N_o equals .157 and assuming each system generates the same level of interference power with I_{oi}/N_o equal to 1.643. If the Constellation system is the first system up and uses RHC polarization, the first interfering system would use LHC polarization and the assumed $ß_1$ equals -4 dB or a factor of .4. The second interfering system would use RHC again and $ß_2$ would equal 1. The third interfering system would use LHC polarization and $ß_3$ equals .4 again. If the Constellation system deploys second then the $ß_1$, $ß_2$, and $ß_3$ values are .4, .4, and 1 because the systems are assumed to alternate polarizations.

From Eq. (19) the value of the maximum realizable downlink capacity M_{mrd} equals 5036 voice channels over CONUS. Using this value in Eq. (27), the capacity results for the assumed levels of background and strong interference are shown in Table B-2 below for the cases in which Constellation system deploys first and second. Recall, that the strong interference levels result by assuming that each other system is transmitting twice as much power toward our desired subscriber unit as we are. On the other hand, the antenna beams are assumed to fall off rapidly outside their primary area of coverage.

From Table B-2 it appears that the downlink capacity of the sharing Constellation system satellite over CONUS when sharing with three other systems will somewhat exceed the 1000 voice channels estimated for the Constellation system operating in its own narrower 2.56 MHz band. However, to achieve this capacity the sharing Constellation system is much more complex than the dedicated Constellation system. It is not clear from this analysis if the extra costs of the sharing Constellation system can be recovered with the same per satellite capacity as in the dedicated 2.56 MHz bandwidth case. Since Table B-2 is based on a strong inter-system interference model, the capacity estimates shown may somewhat under estimate the achievable downlink capacity. The value of polarization isolation is evident since without it the downlink capacity of the Constellation system when sharing with three other systems is only 827 voice channels. Recall that the capacity of the Constellation system is determined by the lower of the downlink and uplink capacity values.

Number of Interfering Systems	CONUS Capacity (Voice Channels)	
	Constellation Deploys First	Constellation Deploys Second
0	4,353	NA
1	2,777	2,777
2	1,453	2,038
3	1,224	1,224

Table B-2. Predicted Maximum Realizable S-Band Downlink Capacity (Strong Interference with Polarization Isolation)

C

APPENDIX C

FEEDER LINK REQUIREMENTS

AND

BAND OPTIONS

APPENDIX C

FEEDER LINK REQUIREMENTS AND BAND OPTIONS

1. Introduction

In its June 1991 application, Constellation proposed to operate its feeder links in the same bands that are allocated for feeder links for radiodetermination-satellite service (RDSS) systems operating in the 1610-1626.5 MHz and 2483.5-2500 MHz bands. These feeder link bands are identified in §25.202(a)(2) of the Commission's rules. Specifically, Constellation proposed to use the 5150-5216 MHz (space-to-Earth) band and the 6525-6591 MHz (Earth-to-space) band for the feeder links for its low earth orbit (LEO) satellite system. Since Constellation proposed to provide radiodetermination services as part of its service offerings, it believed that it is eligible to utilize the bands already allocated for RDSS feeder links.

Constellation's baseline satellite architecture envisions use of a single 2.5 MHz band per service link beam, and 10 L/S-Band service beams in its initial generation of satellites. Figure C-1 illustrates the general frequency plan concept for the Constellation LEO satellites. For Constellation's baseline system, the feeder link bandwidth required for such a satellite architecture can be easily accommodated within the current RDSS feeder link allocations with substantial growth capabilities.

In its Notice of Proposed Rule Making, ("Notice"), the Commission is proposing to require the CDMA applicants to share a common 11.35 MHz band in serving subscriber units in the L/S-Bands. This service link sharing requirement effectively quadruples the amount of feeder link band required. While the feeder link requirements of the initial generation Constellation satellites might still be accommodated with the RDSS allocations, it is possible that future generations of satellites utilizing a greater number of L/S-Band spot beams would require more bandwidth than can be made available in the RDSS feeder link bands even with a modest expansion of the 5 GHz downlink to 5150-5250 MHz.

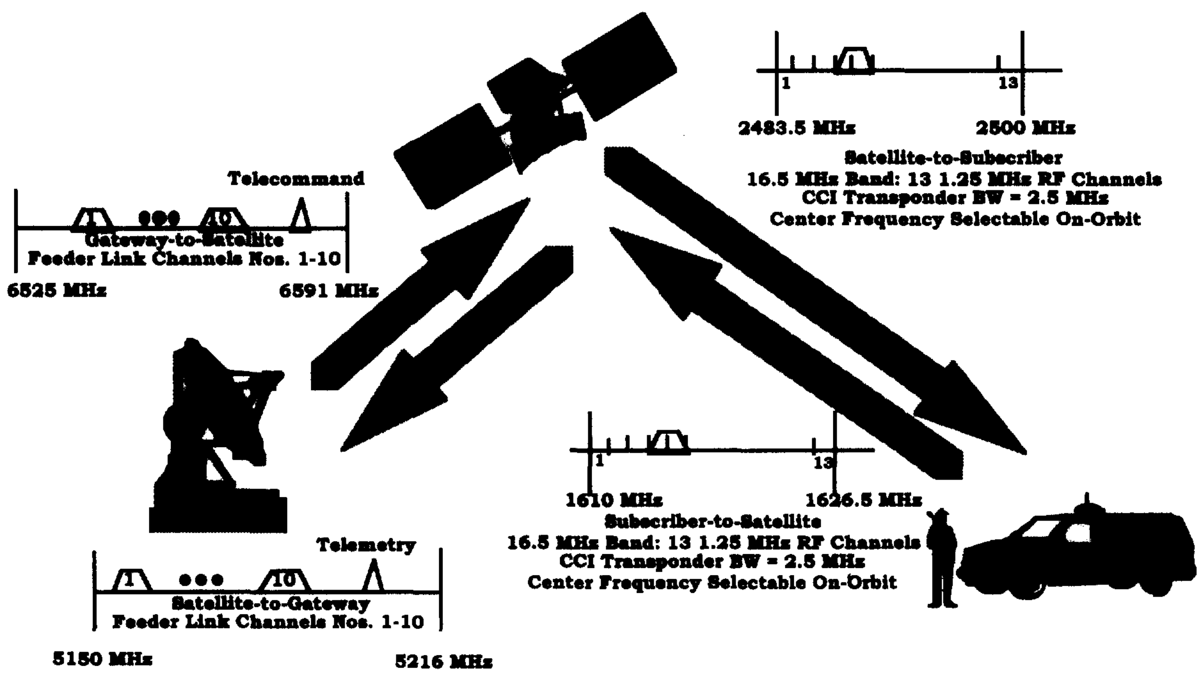

Figure C-1. Constellation 2.56 MHz Baseline Frequency Plan Concept

The Commission also indicated in the Notice that the 5.1 GHz downlink band is not currently available for MSS feeder links, and identified the Ka-Band portion of the spectrum as the most likely alternative. However, use of Ka-Band for Constellation's feeder links will have a significant adverse impact on the design, cost and operations of Constellation's system.

The information in this appendix is provided in support of identifying Constellation's feeder link requirements and the impact of using the Ka-Band as an alternative in the event the Commission is unable to assign the 6.5 GHz and 5.1 GHz bands to the Constellation system for its feeder links.

2. Bandwidth Requirements

Constellation proposes to operate its feeder links with non-steering, earth coverage beams on board the Constellation satellites and high gain, satellite tracking antennas at its gateway earth stations. Constellation's service offerings contemplate multiple gateway earth stations accessing each satellite. Typically, there would be one gateway earth station per country served by the Constellation system. Each gateway earth station site would typically have three or more 6 meter diameter antennas at C-Band that would track the satellites as they pass over the gateway site. At least two antennas are required for traffic handling and at least one backup antenna is required to insure high facility availability. Additional antennas may be installed in order to provide for satellite path diversity/switching. Countries that have a large geographical area visible at a satellite, such as the United States, will have multiple gateway earth stations accessing a Constellation satellite. Conversely, a number of small neighboring countries may decide to share a common gateway earth station. While gateway locations can not be restricted under Constellation's system design, it is not expected that more than about ten gateway earth stations would access a single S/L-band satellite beam at any time in order to keep the beam capacity overhead assigned to signaling and control to a reasonable level. This would correspond to a geographic density of about 4 or fewer gateway earth stations per million square kilometers.

Figure C-2 illustrates several possible feeder link frequency plan configurations. Case 1 illustrates the situation when cross-polarization is not employed within the feeder links. Case 2 illustrates the case when cross-polarization is employed. Where cross-polarization is employed, it is conventional to offset cross-polarized channels so that the center frequency of a radio frequency (r.f.) channel on one polarization falls at the middle of the guardband between two r.f. channels on the opposite polarization which results in some extra guardband being available. This extra guardband can be used to accommodate the frequency band required for telemetry, tracking and command (TT&C) without an additional guardband between the r.f. channel on one polarization and the TT&C channel on the opposite polarization.

Table C-1 presents an estimation of Constellation's C-Band feeder link requirements for its current baseline design. These requirements are calculated using the formulas presented in Figure C-2. The initial generation of 2.56 MHz bandwidth Constellation baseline satellites require a total of approximately 34 MHz under a single polarization feeder link frequency plan and 21 MHz of feeder link spectrum with a polarization frequency re-use frequency plan. Constellation's feeder link bandwidth requirement increases to 78 MHz with cross-polarization frequency re-use under the Commission's proposed L-band sharing arrangement. Note that with reduced guardband assignments, Constellation might be able to just operate within the current 66 MHz RDSS feeder link allocation if it did not offset its cross-polarized channels provided it assure itself of sufficient cross-polarization isolation to eliminate the need for the interstitial channel arrangement. Otherwise, if an interstitial r.f. channel arrangement is needed, an expansion of the RDSS 5.1 GHz downlink feeder link allocation would be required. Constellation could operate up to 8 L/S-band antenna beams under the proposed L-Band sharing

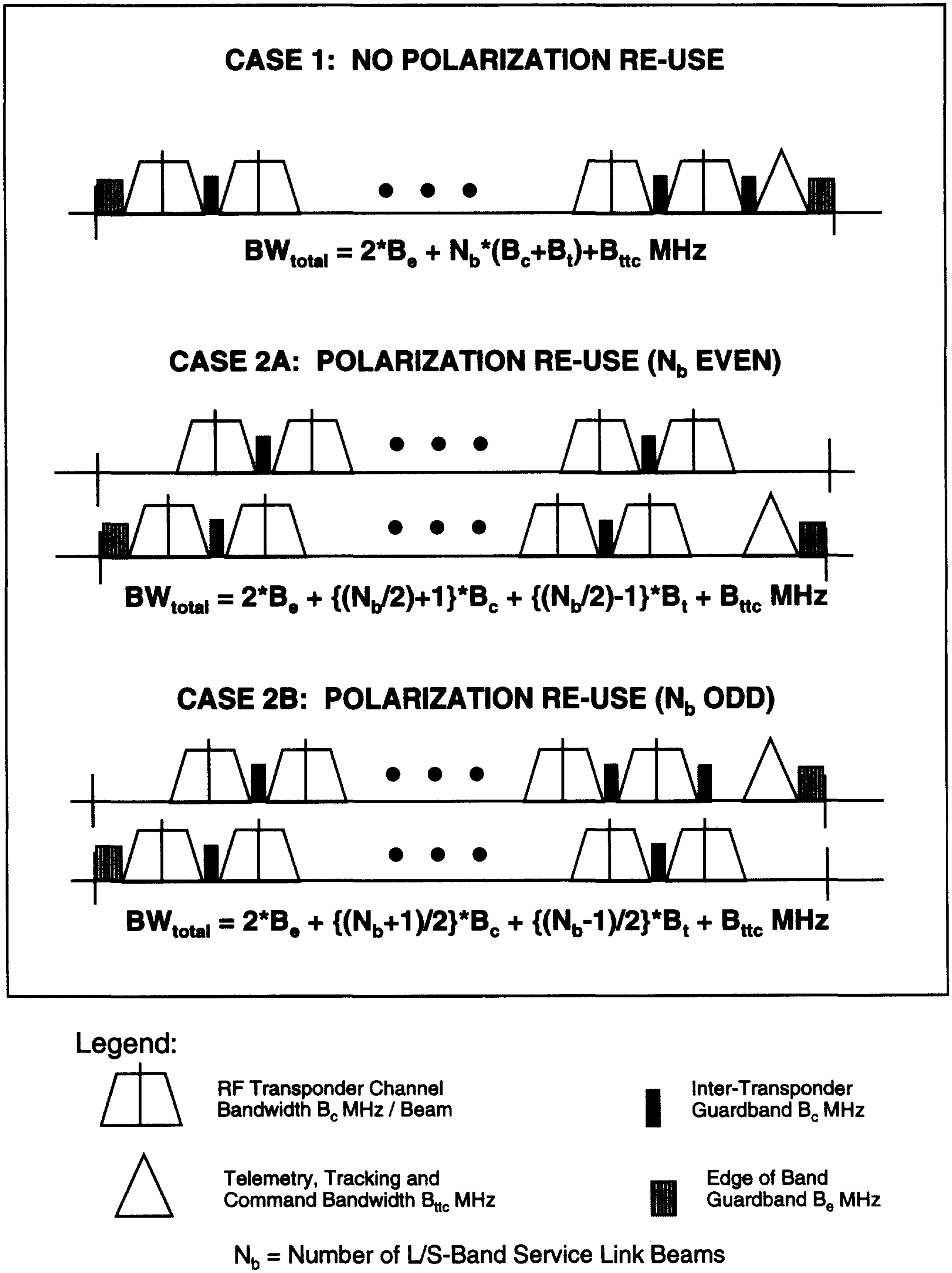

Figure C-2. Feeder Link Frequency Plans

plan if it used the 5150-5216 MHz band for feeder links. This could be increased to 13 L/S-band beams if the C-Band feeder link band were expanded to 5150-5250 MHz as recommended in the NRM Final Report.

	N_b	B_c	B_t	B_e	B_{ttc}	BW_{total}
Baseline No X-Pol	10	2.5 MHz	.5 MHz	1 MHz	2 MHz	34 MHz
Baseline X-Pol	10	2.5 MHz	.5 MHz	1 MHz	2 MHz	21 MHz
FCC Proposal	10	11.35 MHz	1.5 MHz	1 MHz	2 MHz	78.1 MHz

Table C-1. Constellation Initial Generation Feeder Link Bandwidth Requirements

The amount of feeder link spectrum required by future generations of Constellation satellites will be larger as additional satellite antenna beams are added to increase capacity and performance. Thus, it can be seen that the interference sharing approach will have a significant increase on the amount of feeder link spectrum required by the Constellation system.

3. Feeder Link Band Sharing

The bands used for LEO feeder links may be used by satellites in the geostationary orbit as well as by other LEO satellite systems. The NRM considered both of these cases.

Interference may occur between the feeder links used by two different satellite systems when the satellites of the two systems and an earth station antenna beam are directly in line. In the uplink feeder link case, the signals transmitted by one earth station are received by both satellites in line with the earth station antenna beam. In the downlink case, the signals transmitted by both satellites are received by an earth station within whose beam both satellites are located.

This potential for interference occurs only when the satellite of another, interfered-with system is located within the uplink or downlink feeder link beam between the gateway earth station and satellite of the interfering system. Some initial statistics of these occurrences were provided in the course of the NRM committee meetings which indicate that the percentage of time such beam couplings occur is small, but significant enough to have to be taken into account in determining overall link performance, i.e. on the order of 1% of the time. Part of any inter-system coordination process would be to develop beam coupling statistics for the specific orbit constellations of the systems sharing the same feeder link bands.

Constellation has taken the position in the past that it can share the same feeder link bands with other C-band CDMA systems, such as those proposed by Ellipsat and LQSS, provided that proper inter-system coordination of power levels is accomplished. To a first approximation, we can estimate the effects of feeder link interference by calculating the I_o due to interference from a co-channel, equal power interfering LEO feeder link, and combine it with the feeder link thermal noise density, and compare it to the service link C/N_o+I_o. An example calculation, using the baseline Constellation link budget in Table C-2 is presented in Table C-3. As can be seen, the effective link margin drops from about 3.5 dB to about 1.5 dB during beam coupling events. This is a very marginal operating condition. On first impression, however, it appears that coordination of uplink and downlink